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## The use of the BAT instrument on SWIFT for the detection of prompt gamma-ray emission from novae

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**Abstract.** Gamma-rays are expected to be emitted during and immediately following a nova explosion due to the annihilation of positrons emitted by freshly produced short-lived radioactive isotopes. The expected gamma-ray emission is relatively short-lived and as nova explosions are unpredictable, the best chance of detecting the gamma-rays is with a wide field instrument. At the time when the flux is expected to reach its peak, most of the gamma-ray production is at depths such that the photons suffer several Compton scatterings before escaping, degrading their energy down to the hard X-ray band (10s of keV). SWIFT/BAT is a very wide field coded mask instrument working in the energy band 14-190 keV and so is very well suited to the search for such gamma-rays. A retrospective search is being made in the BAT data for evidence for gamma-ray emission from the direction of novae at around the time of their explosion. So far the only positive detection is of RS Ophiuchi and in this case the emission is probably due to shock heating.

### 1. Searches for prompt gamma-ray emission from classical novae

The prompt gamma-ray emission from novae in principle provides a very direct insight into the explosion which is the origin of the outburst and into the nucleosynthesis which takes place (Hernanz 2007). The most intense emission is however expected to last only of the order of an hour and occurs at an unpredictable time, well before the visible detection of the event (Fig. 1). A number of attempts have been made to observe such emission by examining retrospectively data from wide field instruments. Harris et al. (1999, 2000) have reported on searches using TGRS on the WIND mission. Hernanz et al. (2000) examined data from the BATSE instrument on CGRO and Smith (2004) conducted similar searches with RHESSI. None of these searches led to a convincing detection, but none was sufficiently sensitive and complete in coverage that this is surprising.

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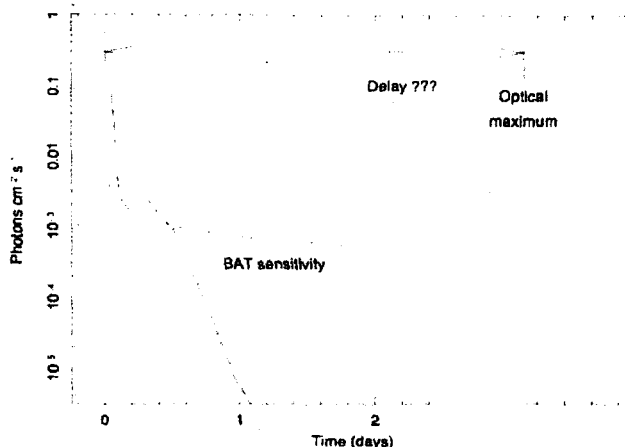


Figure 1. A prediction of the 50–100 keV gamma-ray emission from a CO nova of  $M = 1.15M_{\odot}$  at 1 kpc. The second peak, due to  $^{18}\text{F}$ , is particularly uncertain and recent estimates would place it lower. The emission is expected at a time that is hard to predict before optical maximum. The dashed line indicates the BAT  $5\sigma$  sensitivity as a function of integration time, for a source in the centre of the field of view.

## 2. The Swift mission and the BAT instrument

Most of the gamma-ray photons emitted in the early phases of a nova suffer multiple Compton scatterings before escaping and their final energy is in the range of a few tens, to a few hundred, keV. The expected fluxes are such that a large sensitive area is needed to detect them, even for relatively close events. A very wide field of view instrument is desirable in order to have maximum chance that a nova was in the field of view at the time of the prompt emission. These are very much the same requirements as those which dictated the design of the BAT instrument on the SWIFT gamma-ray burst mission.

The BAT instrument is a coded mask imager with a CZT detector array having a geometrical area of  $0.52 \text{ m}^2$  sensitive in the energy range 14–195 keV. At a distance of 1.0 m in front of the detector is a mask containing 52000 lead blocks, each  $5 \times 5 \times 1 \text{ mm}$ , arranged in a random pattern covering  $2.7 \text{ m}^2$  (Barthelmy et al. 2005). The resulting field of view extends over more than 2 sr, of which 1.4 sr is covered with greater than 50% effective area (Fig. 2). In normal operations onboard software detects gamma-ray bursts within the BAT field of view, either from an increase in counting rate or by differencing successive images, and initiates a slew so that within 20–75 s the narrow field XRT and UVOT can have the burst within their fields of view.

As the directions of novae do not in general correspond to entries in a list of known objects from which variable emission is ignored, a sudden onset of gamma-rays from a nova detected by BAT could in principle trigger such a repointing. But it is more likely that it would not be sufficiently strong or fast to do so (for a discussion of the trigger criteria see Gehrels et al. 2004; Fenimore et al. 2000). However data integrated over time bins of typically 450 s are continually recorded and sent to the ground and can be analyzed retrospectively.

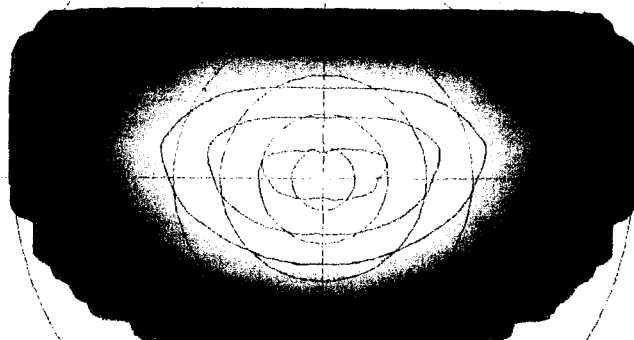


Figure 2. The field of view of the Swift/BAT coded mask telescope. The circles indicate off-axis angles of 10, 20, 30, 40, 50, 60°. The contours correspond to 100, 75, 50, 25, 0% effective area.

When a nova is discovered visually it is possible to go back and examine the data corresponding to its position on the sky. The sensitivity for the detection of emission from a known position is appreciably better than that for a totally random occurrence such as a burst or a transient because the ‘number of trials’ is much smaller.

Fig. 1 shows the BAT sensitivity as a function of integration time compared with an example of a prediction of the gamma flux from a nova. At first sight this implies that detection of the initial short peak of emission (due to  $^{13}\text{N}$ ) should be easy and that of the second peak due to  $^{18}\text{F}$  perhaps possible. However several factors need to be taken into account (i) in Fig. 1 the nova is assumed to be at 1 kpc, but most will be more distant (ii) the sensitivity is given for the centre of the BAT field of view and it is not as good towards the edges (Fig. 2) (iii) on short time-scales, the probability that the nova is within the field of view is only  $\sim 10\%$  (iv) on longer time-scales coverage becomes more and more certain, but the integration time will be less than the elapsed time.

Results of searches in the directions of known novae at around the time of the expected emission are presented elsewhere in this volume (Senziani et al. 2007). So far these are negative but none of the novae have occurred sufficiently close that a detection would have been expected.

### 3. RS Ophiuchi and the future

Some of these points are illustrated in Fig. 3 which shows the actual coverage obtained in the case of the recurrent nova RS Ophiuchi.

The detection with BAT of hard X-ray emission from RS Ophiuchi at around, or even before, the time of the visual discovery (Bode et al. 2006) provides a demonstration of the efficacy of the approach adopted in the SWIFT search. In this case the emission cannot be due to downgraded radioactive decay gamma-rays (Hernanz 2007; Senziani et al. 2007). It was presumably due either to shocks between the ejecta and surrounding wind material, as suggested by (Sokoloski et al. 2006) as the explanation of the emission detected later with RXTE, or given its early onset, to internal shocks in the ejecta themselves.

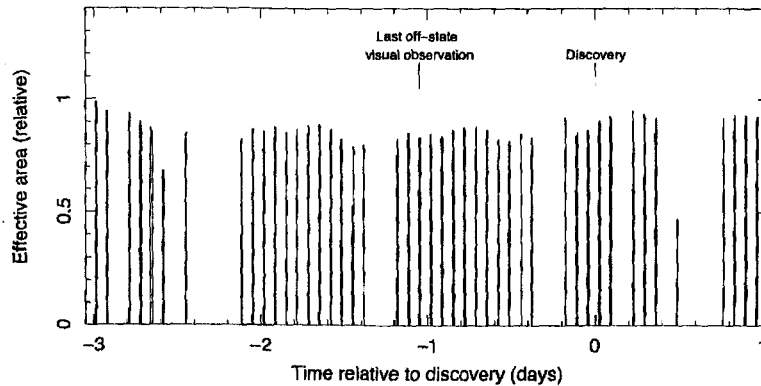


Figure 3. Example of the coverage of a nova by BAT. Data are for RS Oph. Individual observations are typically  $\sim 10$  min and spaced by the orbital period (96 min). The effective area during each observation depends on where the object falls within the field of view.

A detailed analysis of the probability that during the anticipated long operational life of the Swift mission BAT will permit the detection of prompt gamma-rays from a nova is in preparation. If the mission continues, as is hoped, for say 10 years, the chance of a detection is quite promising.

In the (even) longer term, the proposed EXIST 'Black Hole Finder Probe' mission (Grindlay 2005; Hernanz & José 2004) will have more than 10 times the collecting area of BAT and will sweep the whole sky performing a complete hard X-ray survey every 95 minutes. Thus any nova is certain to fall within its field of view during the initial peak of the gamma-ray emission. In addition, its energy range (10–600 keV) will cover the 511 keV line, providing valuable diagnostic information about those positron annihilation photons which escape without losing energy through Compton scattering.

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